

**Woods Hole
Oceanographic
Institution**



**Water Samplers for Open Ocean
Tracer Release Experiments**

by

Terence Donoghue
James R. Ledwell
Kenneth Doherty

December 1998

Technical Report

Funding was provided by National Science Foundation under
grant numbers OCE-9020492 and OCE-9415598.

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INTRODUCTION

Conventional "spot" sampling of patchy distributions of oceanic constituents can lead to sampling errors. Interpretation of results based on data of disparate temporal or spatial resolution can be difficult or impossible. This report discusses the design and performance of two sampling devices which attempt to minimize these problems. The devices were created as part of the North Atlantic Tracer Release Experiment (NATRE) and were used again in the Brazil Basin Tracer Release Experiment, but can be used for other experiments where inhomogeneity is anticipated.

The first sampler is a mechanically-operated, variable-rate integrating water sampler which acquires a time-averaged sample. The sampler incorporates features of both the spring-driven and the hydraulically-driven samplers described by Ledwell et al., 1991. The impetus to redesign the sampler was the desire to acquire larger volumes for analytical purposes for NATRE and to improve reliability.

The second sampler is a multichamber sampling system incorporating a battery powered pump and valve system made by McLane Research, Inc., of Falmouth, Massachusetts. The system consists of a micro-gear pump, a 50-port valve with programmable controller, and carousels containing fifty glass sampling syringes. It can be programmed to sample on a variety of schedules allowing the user flexibility in the field to adapt to changing requirements.

North Atlantic Tracer Release Experiment

One of the primary objectives of NATRE was to directly measure

diapycnal diffusivity in the thermocline of the North Atlantic subtropical gyre. Sulfur hexafluoride (SF_6), a non-toxic gas harmless to marine organisms, was injected at about 300 m along an isopycnal in a series of streaks spread over an area of approximately 600 km² west of the Canary Islands. SF_6 can be detected at levels of less than 0.1 femtomolar by electron capture gas chromatography. The anthropogenic background concentration of SF_6 in the upper ocean is on the order of 1 fM. As a result of this combination of factors, the tracer patch could be tracked over a period of several years while the concentration was diluted by several orders of magnitude below its initial level. A systematic analysis of the evolution of the tracer distribution over time allowed various vertical and horizontal dispersion coefficients to be calculated. Ledwell et al., 1993 and Ledwell et al., 1998 describe the overall experiment and its results, while this report focuses on the tracer sampling equipment.

In an early phase of the experiment, it was expected that conventional spot sampling could not be used effectively on the initial tracer streaks. Thus, a specialized array was deployed (Fig. 1) to sample the tracer distribution. At the center of the array was a sampling sled containing a CTD, a Niskin bottle rosette, the multichamber sampler, and two integrating samplers (Fig. 2). Approximately 24 integrating samplers were also spaced at 2-15 m intervals above and below the sled to assess the vertical spread of the tracer patch. This array was towed through the patch with the CTD providing feedback to the winch to enable the sled to remain within a few meters of the targeted density surface while the various samplers

filled. SeaCat CTD's were also hung on the wire above and below the sled to characterize the vertical gradients in the density field as the array was towed.

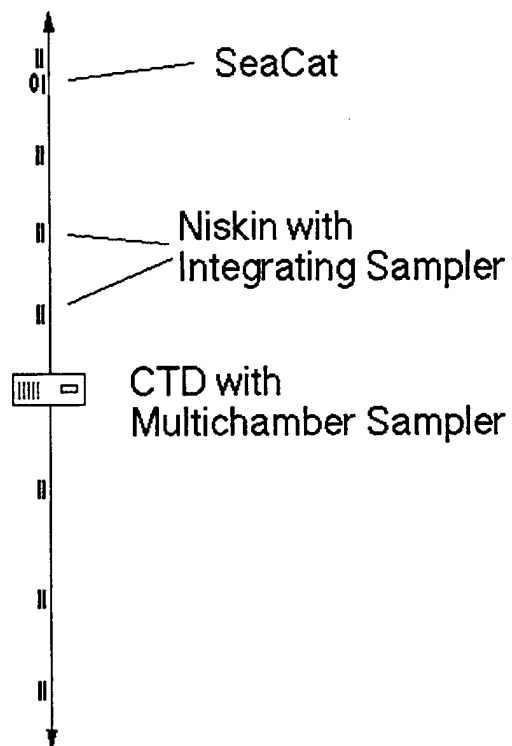


Figure 1. Schematic of the sampling array used in the NATRE experiment.

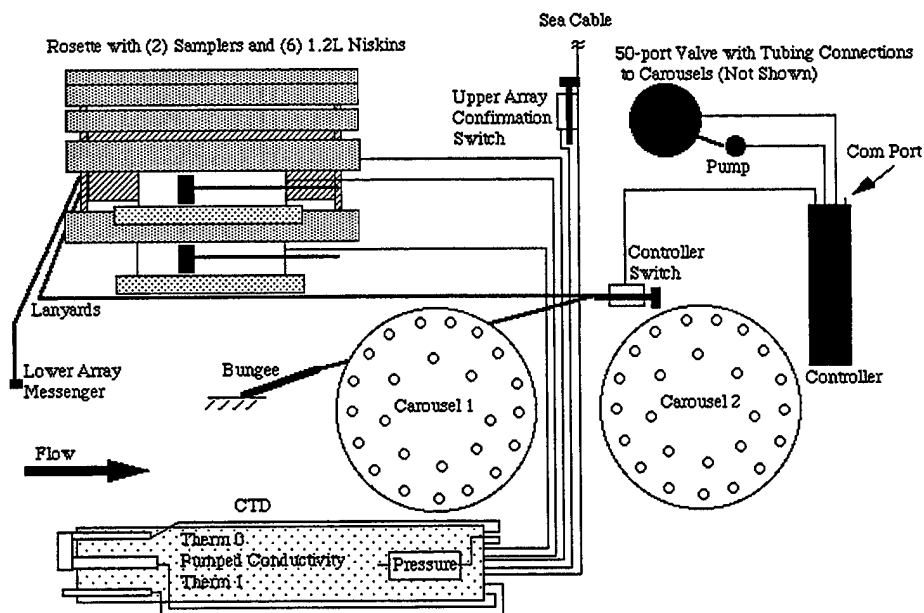


Figure 2. Schematic of the equipment on the sampling sled in NATRE.

INTEGRATING SAMPLER

General Description

In its present configuration (Fig. 3), the sampler is mounted with two stainless steel hose clamps on the side of a General Oceanics 5-liter Niskin bottle. The Niskin/sampler is attached to the hydrographic wire and lowered to the desired sampling location. Initially, the sample canister has clean "hydraulic water" outside an evacuated sample bag and the cylinder is empty. The sampler lanyard, which is cocked in one of the Niskin release pins, is released by a mechanical messenger. Constant tension springs attached to the piston pull the piston up, lowering the pressure inside the cylinder. Hydraulic water then flows from behind the sample bag into the cylinder at a rate controlled by an adjustable capillary restriction in the hydraulic line. The hydraulic water pulled from the sample canister is

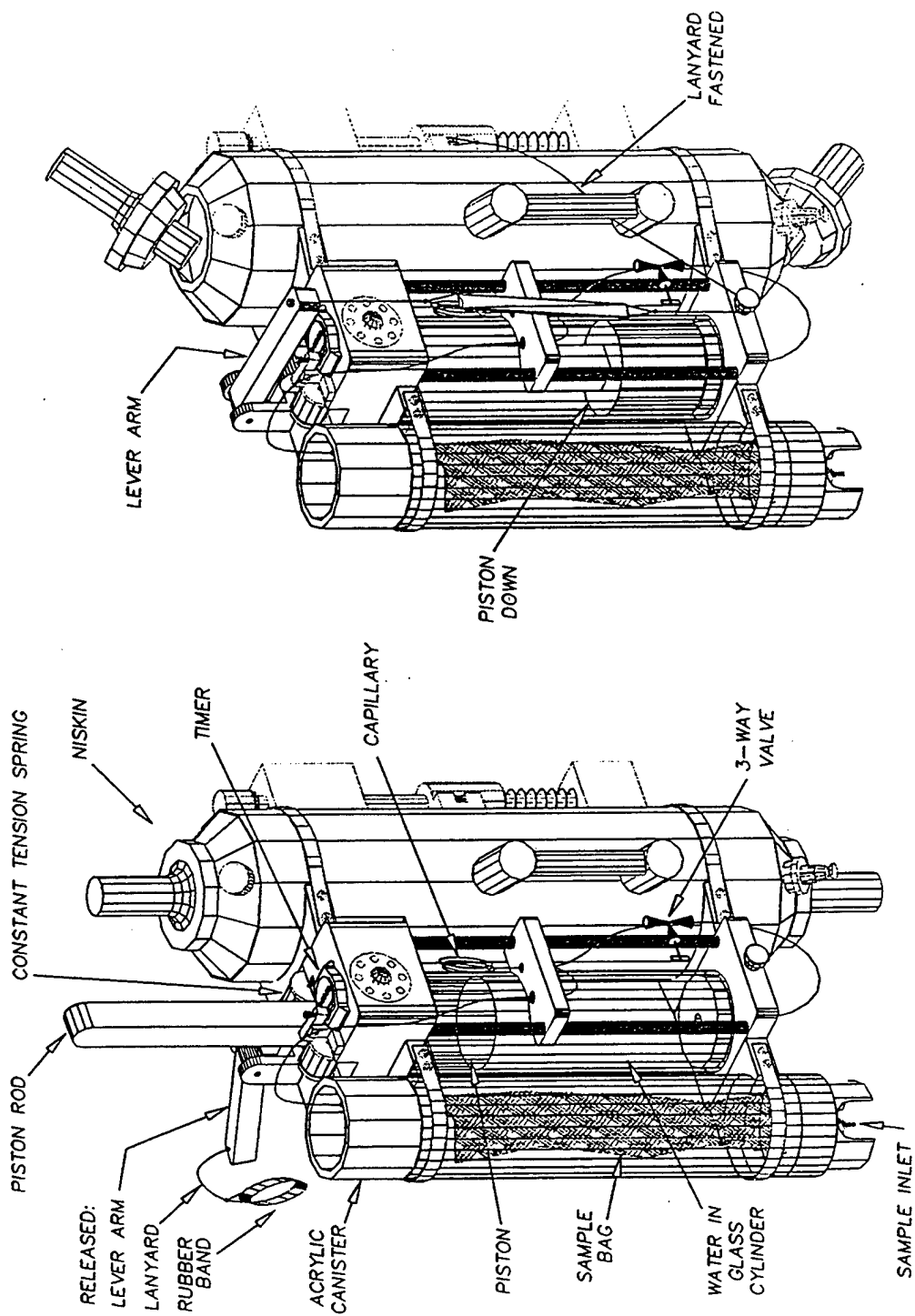
replaced by an equal volume of seawater which flows into the sample bag. Sampling stops and the cast is retrieved when the piston finishes its stroke. Fill time is recorded by an oil-filled stopwatch attached to the sampler. The stopwatch is started before deployment and stopped when the sampler finishes filling. On recovery, the sample canister is replaced with a fresh one and removed to the laboratory for analysis.

The initial sampling objective for NATRE was to retrieve an 850 ml sample over a transect of 3-8 hours duration, 6-35 km length, and approximately 300 m depth. This approach was designed to average over the small-scale patchiness in the tracer distribution. Averaging was achieved by filling a set of samplers at a slow and approximately constant rate while towing the center of the sampling array at a constant speed along the targeted isopycnal surface.

The integrating samplers can be used to integrate concentration in a number of different operational modes. Fill times can be adjusted from as little as 2 minutes to about 9 hours. Experience and testing at the approximate pressure (41,340 kPa or 6000 p.s.i.) and temperature (0°C) of 4000 m depths indicate that overall sampler reliability decreases as these conditions are approached. The crystal in the oil-filled stopwatch collapses and the piston sealing rings in the cylinder leak intermittently under these conditions. Thus, 3500 m should be viewed as a maximum practical operating depth, although the samplers were used with partial success at 4000 m in the Brazil Basin (Polzin et al., 1997).

The cylinder endcaps and piston head are machined from Delrin® blocks. The piston head has spring-loaded teflon sealing rings and is

contained in a glass cylinder. The inside diameter of the glass cylinder is drawn to a tolerance of 0.05 mm. The acrylic sample canister contains the sample bag, a polyethylene-mylar-polyethylene layered sandwich designed for gas permeation resistance, durability, and chemical inertness. Alternative bag materials could be employed for different sampling requirements. All the remaining parts of the sampler are machined plastic while the hardware is either titanium or stainless steel for corrosion resistance and strength. Materials and machining for 33 samplers cost about \$36,000 in 1992. Appendix B lists parts and suppliers for the integrating sampler.



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Figure 3. Integrating sampler mounted on a 5L Niskin. The sampler is shown on the right in its cocked configuration and on the left as it finishes sampling.

Preparation and Use of the Integrating Sampler

Preparation of the samplers for deployment or turnaround consists of two main processes: canister preparation and "priming" of the sampler cylinders. Any prior sample must be evacuated from the sample bag within the canisters while fresh hydraulic water is introduced behind the bag. Once the bag is evacuated and the hydraulic water refilled, 10-15 ml of clean water ("backfill water") is allowed to partially refill the bag in order to mechanically relax the bag and provide a reservoir of water eventually used to displace any air in the canister's valve upon deployment. As will be discussed below, this backfill water helps minimize air bubbles in the samples. For the sampler cylinders, the hydraulic water from the previous cast must be exhausted to a pre-set level of approximately 50 ml before the sampler lanyard is secured. The 50 ml at the head of the piston allow for the contraction of any air left in the hydraulic lines and acts as a hydraulic cushion that enables positive pressure to be introduced in the hydraulic lines upon deployment. Finally, the canister must be connected to the piston and the sampler watch reset for the upcoming cast.

The sampler is deployed by attaching the Niskin with sampler and messenger to a hydrographic or CTD wire, securing the sampler lanyard to a Niskin release pin, and opening the canister valve. Backfill water then drips out the canister valve as the force of the stretched rubber band in the sampler lanyard pushes some of the 50 ml of water left in the cylinder through the hydraulic lines into the canister volume behind the sample bag. This feature of positive pressure in the hydraulic lines minimizes the trapping of air bubbles inside the sample

bag or canister valve.

The samplers are fired by sending a standard Niskin messenger down the hydrographic wire. The sampler array is then towed along the desired transect, profiled or left to fill depending on the mode of operation until the preset fill time of the samplers is reached. The array is then retrieved. The canister valve is closed as soon as the sampler reaches the ship's rail. Sampler identity and position are verified and the fill time is recorded. Samplers are placed in wall-mounted racks designed to secure the Niskin/sampler in an upright position. With a sufficient number of personnel (3-4), sampler turnaround and sample analysis can commence while the cast retrieval is in progress.

Approximately 2-4 person-hours are required to ready 30 samplers and canisters. The time required is mainly a function of sampler maintenance schedules and operator experience. In NATRE, two sets of sample canisters were ready for use. This allows a fresh set of canisters to be deployed on the recocked cylinders and leaves canister preparation to be performed while a cast is in the water. In this case, only 30-60 minutes is needed between casts.

Integrating Sampler Performance Analysis

Fill Times

Laboratory tests of sampler performance consisted of immersing the samplers in a container filled with fresh water. The samplers were then activated and their performance monitored. Overall fill time was recorded for each sampler for each trial. Two of the samplers were monitored continuously with a potentiometer geared to a track on the

piston rod, while piston stroke was occasionally measured on the other samplers.

Field test data were accumulated from actual deployments made during NATRE. Again, fill times were recorded for each sampler and two samplers on the sampling sled were equipped with the geared potentiometers wired to a CTD sampling channel for real-time feedback.

Sampler performance differed in field and laboratory tests. Lab tests showed a relative standard deviation of fill time of only 2.3% while the field runs had an overall relative standard deviation of approximately 12% for two 30-day sampling cruises. Although ambient conditions for the lab test (Fresh water, 6°C, 1 dbar) were different from field conditions (36.2 ppt, 15.6°C, 310 dbar) the following comparisons suggest possible sources for the additional error in the field.

Fill times within a cast in the field were very inconsistent. Fill times for a particular sampler from cast to cast were more consistent but showed a trend of lengthening over time. At first, it was assumed that the samplers were not working properly due to a build up of salt and other materials in the sampler and associated tubing. This would not have been the case in the lab tests because the samplers were new and the tests were done in fresh water. Based on this assumption, the samplers were taken apart and cleaned with isopropyl alcohol with little effect on the fill times. A test was done to see if the samplers' hydraulic system was leaking. All of the samplers were lowered, allowed to partially fill and then retrieved. The volume of water that each sampler took and the piston stroke for each sampler

were measured. The sampled volumes were within 3% of the expected volumes based on piston stroke, indicating that even though the fill times were erratic piston displacement corresponded well with sample intake. Then, all of the capillaries on the samplers were replaced, with the result that the fill times were more consistent among different samplers within a cast, and the average fill time approached the range expected from calibrations done in the lab and consistent with Poiseuille's Law. These results led us to hypothesize that the capillary tubing was biofouling or swelling over time.

A maintenance schedule was implemented which consisted of cleaning the pistons with isopropyl alcohol approximately every sixth cast and changing the capillary on any sampler that demonstrated poor performance. Although the desired fill time was achieved (7.5 hours) with an approximately 5-10% relative standard deviation by individually tuning the samplers, considerable effort was required to achieve these results.

Watch-Stop Mechanism

A concurrent problem was the fact that many of the samplers' stopwatches were not stopping at the completion of filling. The sampler watch malfunction rate of 45% was essentially the same in both the lab and first field trials. It was hypothesized that the watch-stop mechanism setting was being altered in situ by the vibration of the hydrowire. The watch screws, which fine-tune the point at which the mechanism pushes the watch stop button, were set and glued in

position with silicon cement on some of the samplers but this had little affect on the success rate of the watches.

There were indications in laboratory tests performed after our first sampling cruise that impulse actuation of the watch button would prove reliable. The watch-stop mechanism was redesigned for our second sampling cruise so the watch-stop button would be actuated by an impulse rather than the slow depression used on our first cruise. The malfunction rate decreased from 45% on the first cruise to 30% on the second cruise. Although the success rate improved, the mechanism was still not completely reliable. Further design work is needed on this mechanism to improve its performance.

Sampler Sensor Results

Samplers on the sampling sled, called SAM 1 and SAM 2, were fitted with a sensing device which provided an analog voltage proportional to their percent fill. Sensors were 10-turn potentiometers geared to the piston stroke. The voltage was fed through a channel on the CTD to provide real-time feedback on the performance of these two samplers. Unfortunately, these sensors failed due to water leaks on several occasions. It appeared that the o-ring seal around the potentiometer shaft was unreliable because of side loading on the shaft. The sampler piston rod had a gear track which engaged another gear on the potentiometer shaft. Since the piston rod stroke path was not rigidly constrained, the gears were not necessarily properly aligned each time. The sensor also provided some additional

resistance to the piston stroke which would slow the fill relative to a sampler without a sensor. Despite these problems, data were obtained on how the samplers filled over time both in a laboratory setting and in the field.

The laboratory procedure consisted of running the sampler with sensor in a barrel of clean fresh water and recording the voltage output of the sensor. SAM 1 and SAM 2 also provided data in the field as part of the central sampling sled (Figure 2). Figure 4 shows the variation of voltage with time and a box-averaged slope of this curve which is proportional to the fill rate. Note the gradually decreasing slope, or fill rate, as the sampler fills. This is in part a reflection of a subtle decrease in spring tension. However, this decrease represents less than a 10% change in fill rate over the 4.5 hours of sampling. The sampler was effectively filled at 4.4 hours and the rapid drop is a result of the sampler completing its stroke. Similar results were obtained in the laboratory and in the field. It is difficult to directly compare data from widely varying fill times and ambient conditions but the pattern of nearly constant filling persisted throughout. Also, as was expected, the fill rate decreased in general as temperature decreased due to increased viscosity.

Sled Duplicates

The concentrations of SF_6 from side-by-side samples taken on the sled for each cast during the first cruise were compared. Sample concentrations from the sled duplicates were within about 17% of the mean sled concentration for each cast. The difference between the two samples is probably largely attributable to the fact that SAM 1 filled faster than SAM 2. In a streaky tracer distribution, the sample concentration would vary by acquiring more or less volume within a high concentration streak. This points to the fact that, despite the integrating feature of this type of sampler, a statistically representative number of samples is still required to acquire a clear picture of the average vertical distribution of a horizontally streaky tracer field.

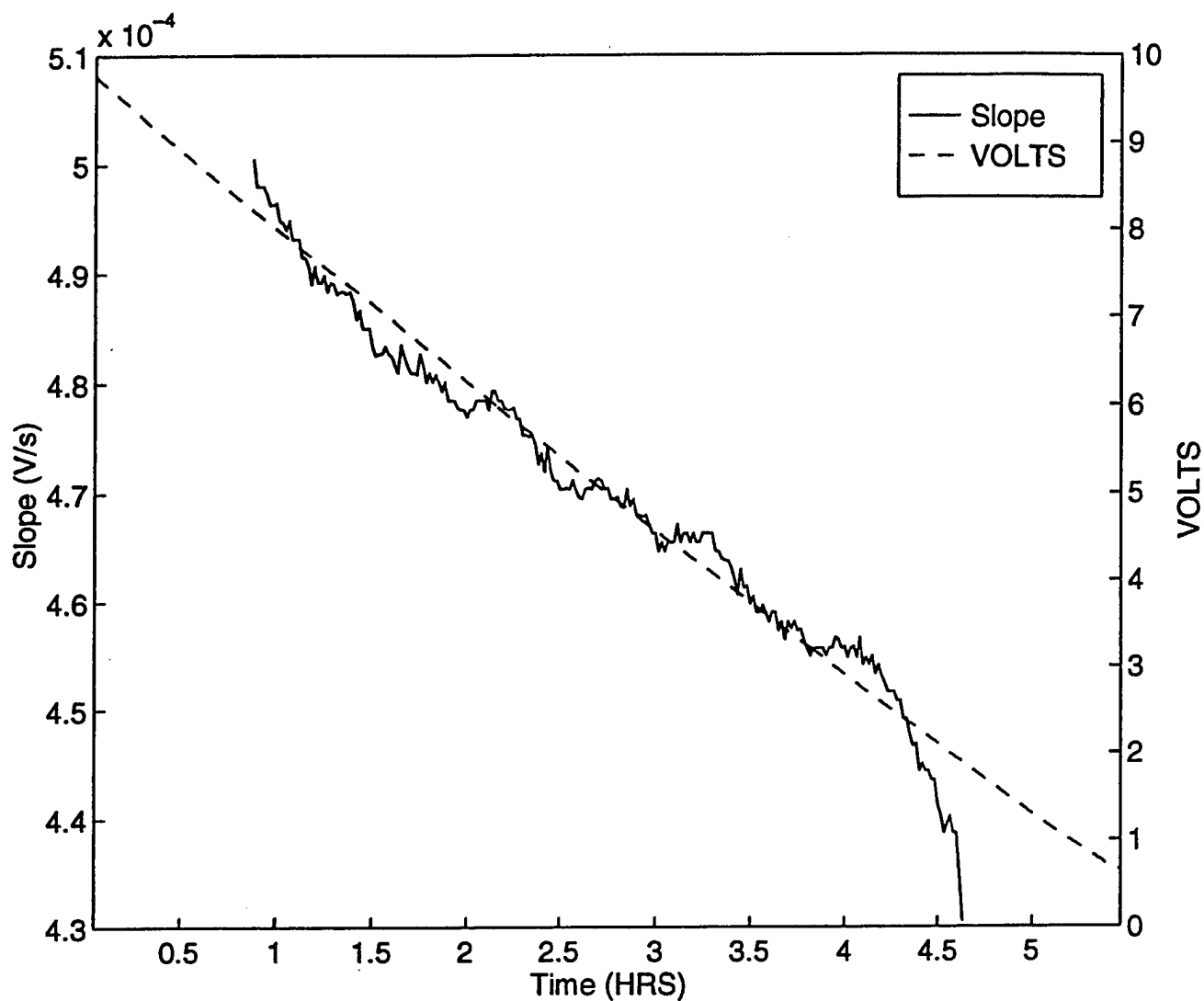


Figure 4. The dashed line shows a typical plot of sampler sensor output voltage versus time. The voltage slope, which is proportional to fill rate, is also shown. The slope curve has been box-averaged ($t=1000$ s) to show the general trend while smoothing out high frequency noise inherent in the slope calculation.

Sample Bag SF₆ Memory

It was discovered early in the development of the samplers that the sample bag material, a polyethylene-mylar-polyethylene layered sandwich, had a slight affinity for SF₆. Many alternate bag materials were tested. Candidate materials had to possess low air permeability (of order $<10^{-8}$ ml cm⁻² s⁻¹ at 101 kPa (1 atmosphere) differential pressure), mechanical strength in flexion, and wall thickness less than 0.01 cm. The test bags were made from commercially available stock materials.

Memory tests were typically performed by storing a SF₆ spiked water standard for at least 8 hours in a canister equipped with a bag made from the test material. The standard water would be forced from the bag by collapsing the bag with a water head of approximately 13 kPa. The bag would then be backfilled with an aliquot of nitrogen and left to sit for at least an hour before analysis of the backfill nitrogen was performed. The volume extracted from the bag was consistently within 3-5 ml of what was drawn into the bag. Even if as much as eight milliliters of the standard water were left behind, it would represent less than 1% of the total mass of SF₆ originally placed in the bag. A SF₆ mass balance was computed by comparing the amount in the standard water initially in the bag with the amount remaining finally plus the amount found in the nitrogen backfill. There was no detectable SF₆ concentration in the water surrounding the bag during the tests. In addition, it was observed that the one hour nitrogen backfill of the bag was nearly 100% efficient at removing the residual SF₆; a second nitrogen backfill of the bag contained virtually no SF₆.

Based on these observations, "memory" was operationally defined as the percentage of SF_6 from the original water standard found in the nitrogen backfill.

Table 1 is a summary of results of bag material memory tests. In practice the canister and piston walls do not come into contact with the sample but the results of their tests are included. The acrylic memory represents a canister without any bag material. The piston memory is for the piston chamber. All of the alternate bag materials possess some degree of memory for SF_6 . It seems that SF_6 is either being adsorbed by the materials or is being sequestered within the laminate layers of the bag or both. Since a memory-free alternative bag material was not found, use of the polyethylene bags continued. The memory effect is included in data analysis and canister bags are purged with nitrogen as needed to minimize cross-contamination between successive samples.

Material	Memory (%)
Canister (Acrylic)	3
Delrin® (Piston)	6
Polyethylene coated mylar foil (Sampling Bags)	5-6
Nylon	7
Nylon coated foil	12
Saran®	27
Saranex®	10
Teflon®	28
Tedlar®	14

Table 1. Summary of memory tests for various materials.

Integrating Sampler Summary

The sampler has several advantages and disadvantages.

The advantages are:

- 1) Integration in time or space for dissolved constituents to 3500 m depth,

- 2) Reusable corrosion resistant components,
- 3) Ease of maintenance and use,
- 4) Interchangeability of sample containers,
- 5) Low cost.

The disadvantages are:

- 1) Uncontrolled variability of fill rate and fill time,
- 2) Lack of real-time feedback on performance for most of the samplers in the array,
- 3) Limited post-sampling feedback on performance, particularly when watches fail,
- 4) Adsorption of SF_6 onto canister bag material.

MULTICHAMBER SAMPLER SYSTEM

General Description

The multichamber sampler system is shown schematically as part of Fig. 2. Each of the carousels is an aluminum ring and stand with a Delrin® collar. Polyethylene clips around the ring help support twenty-five 100-ml glass syringes in each carousel. The syringe pistons were cut so they can slide through the 60 ml fill mark within the syringe barrel without protruding beyond the barrel. The shortened pistons allowed a one-hole rubber stopper to be placed with attached 1/8" tubing in the back end of the barrel to seal and connect the

hydraulic plumbing. When all the syringes are in place on the ring they are held captive on the collar by a nylon platen exerting pressure on their stoppers.

The McLane Research pump is a micro-gear pump capable of reliably delivering between 5 and 250 ml/min, but for the purposes of the tracer release experiments, it was used near its lowest pumping rate. Only filtered water is drawn through this pump because of the very fine gear size (0.017 ml/rev). Therefore, only water of known quality is pumped from the back side of the syringe pistons through the 50-port valve. The 50-port valve has a stator with a single common port on an annulus and fifty ports spaced around the annulus. A groove on the rotor connects each of the fifty ports in sequence to the common port of the annulus on the stator. A stepper motor is connected to the rotor to precisely control alignment as it switches ports on command. A separate module contains the batteries (including a data backup battery), a stepper motor driver board, a pump driver board, a power regulation board and a programmable Tattletale® board as an interface between the hardware and a BASIC control program. This control module has electrical bulkhead connectors to link with the pump and valve motors and a serial communications port to program sampling schedules, acquire performance data, and do systems tests from a PC. In addition to sampling on a preset schedule, as done in the tracer release experiments, the multichamber sampling system can be set up to sample on a remote trigger or a combination of scheduling and triggering. A laptop computer was used for programming the system and retrieving the pump record on deck between deployments.

For the tracer release experiments, the sampler was programmed to

sequentially acquire fifty 60 ml samples, each in approximately 11 minutes, and thereby get a series of abutting integrals of concentration along the path over which it was towed. In contrast to the integrating sampler described above, which integrated over kilometers, each syringe of the multichamber sampler integrated over a path of 300 to 600 m. The system was mounted aboard the sampling sled to connect tubings between the syringe carousels and the fifty-port valve. One of the last operations before deployment was to open the syringe valves by hand. Pressure on the stoppers from the platen insured that water flowed from the syringes and out the valves, keeping them clear of air. The valves remained open until the sled returned to the deck after sampling. Then the sled was lowered and stabilized on the targeted density surface. The remote trigger to start the multichamber sampling system was a magnetic switch which was mechanically closed upon firing a specific rosette position at the start of a transect. The pump drained away an aliquot of the filtered water behind each syringe piston in turn and, in the process, an equal volume of sample seawater was acquired in the syringes.

The multichamber sampler is a versatile system that can be used in time-series, event-sampling, profiling or integration modes. The whole system is water-tight to 5500 m, has proven rugged in the field, is made from non-corrosive materials and cost around \$10,000 in 1997. The pump, valve and controller can be purchased from McLane Research, Inc. in Falmouth, Massachusetts, while the syringe carousels and tubing were fabricated from stock aluminum and components available from most scientific supply houses.

Preparation and Use of the Multichamber Sampler System

Preparation of the multichamber sampler system for deployment is relatively simple after the initial setup. Since the pump will not overcome a jammed syringe piston, each syringe piston must slide smoothly in its barrel before deployment. Unfortunately this is not always the case, especially on the initial setup when the unused syringes are stored dry. The syringes seem to operate more smoothly with continual use and careful attention to cleanliness. One potential source of confusion can be the connecting of the fifty syringe tubings to the multiport valve ports. Errors can be minimized by establishing a systematic way of connecting the tubings in the order of firing. The pump, valve, tubing and syringes should be free of air before deployment. The pump should only pump water since air is not a sufficient lubricant for its gears. Even air bubbles, which one could safely assume to be dissolved at depth, present a problem since a volume of seawater equal to that of the bubbles would be taken through the open syringe valve as they dissolve, diluting the sample. Air is eliminated from the system by careful flushing and priming of all the working spaces prior to deployment. If all goes well, the pump and valve only need to be primed once, but the syringes and tubing must be carefully prepared each time. With practice, a carousel of syringes can be prepared in about 30 minutes. Set up of the control computer and program consists of verifying or changing the sampling schedule, checking battery voltage and other housekeeping parameters, and putting the controller in sleep mode to await the trigger signal from the magnetic switch. The sampler is then ready for deployment.

Multichamber Sampler Performance Analysis

Analysis of the performance of the multichamber sampler is somewhat anecdotal because there is little quantitative feedback available. Also, many of the problems with the sampler over the course of several cruises have been subsequently fixed, since the sampler is an evolving prototype. Originally, the valve only had 18 ports and the alignment and programmed control of the valve was not completely reliable. As a result, a complete set of samples was obtained on our first sampling cruise for only 29 of 37 casts. Eight of the casts had problems such as missed samples, late pump starts, or partially filled samples. On the second sampling cruise, the valve was expanded to 50 ports and the software was improved. However, it was sometimes necessary to mechanically force the valve to its "home" position with a screwdriver. Also, partial fills or skipped fills continued to be a problem. For the third cruise in April/May '93, the software was modified to allow keyboard controlled valve alignments and the valve was equipped with a microswitch to indicate exactly when the valve was in the "home" position. With the exception of a couple of syringes which only partially filled, the pump and valve worked well. The partial fills were thought to be related to the valve not aligning at a port properly or syringe pistons getting stuck in their barrels. However, periodic post-cast examination of the partially filled syringes showed little evidence that this was generally the case. Enhancements to the multichamber sampling system in September 1994 included external event triggering or scheduled sampling, field adjustable pumping rate ranges, faster valve movement to minimize time between samples, optimized valve alignment, and a memory backup

battery. Use at 4000 m acquired only 72% of the scheduled samples on three deployment in 1996. Another deployment to 2000 m in 1997 achieved mixed success below 1500 m. Subsequent analysis at McLane Research of the mechanics of the pump and valve pointed to wear of the rotor which resulted in the loss of the seal inside the valve.

The pump and valve will not run when battery voltage falls below 18 V. Field experience has shown that a new battery, starting at 31.5 V, will last for approximately 100 hrs of pumping at 6 mls/min. The 9 V backup battery keeps the schedule and data available in memory for about six months after the main battery has been spent. The main battery pack was replaced when its voltage fell to about 20 V.

REFERENCES

- Ledwell, J. R., A. J. Watson, and C. S. Law, Mixing of a tracer in the pycnocline, *J. Geophys. Res.*, 103, 21499-21529, 1998.
- Ledwell, J. R., A. J. Watson, and C. S. Law, Evidence for slow mixing across the pycnocline from an open-ocean tracer-release experiment, *Nature*, 364, 701-703, 1993.
- Ledwell, J. R., A. J. Watson, K. W. Doherty, and W. M. Berelson, Integrating samplers for the deep sea, *J. Geophys. Res.*, 96, 8727-8732, 1991.
- Polzin, K. L., J. M. Toole, J. R. Ledwell, and R. W. Schmitt, Spatial variability of turbulent mixing in the abyssal ocean, *Science*, 276, 93-96, 1997.

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APPENDIX A
Laboratory and Deck Protocols

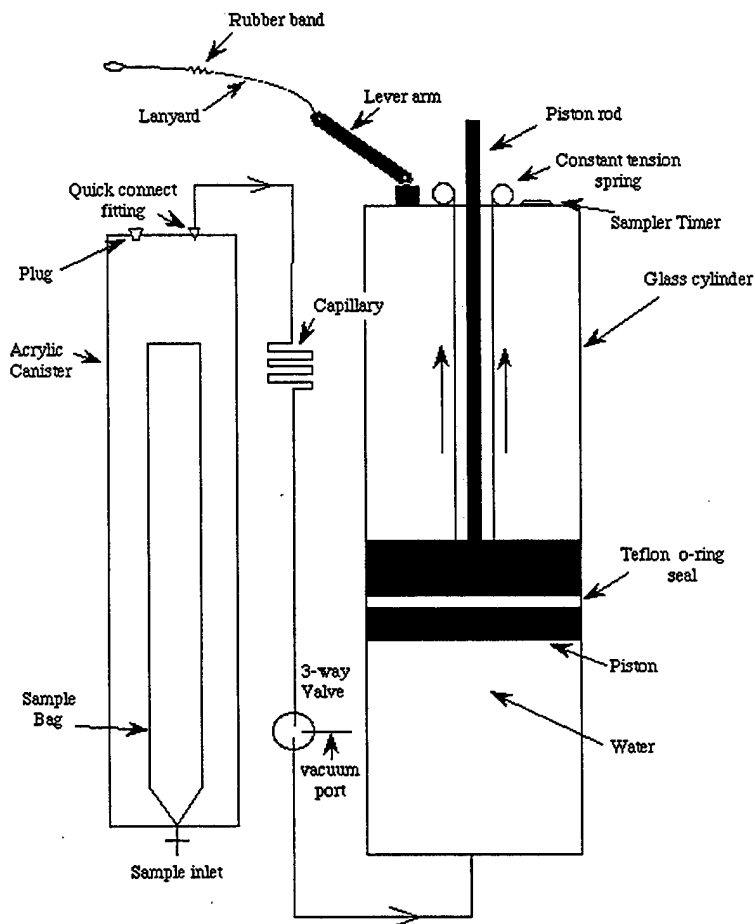


Figure 5. Schematic view of the integrating sampler.

I. INTEGRATING SAMPLER PREPARATION

Initial preparation of samplers for deployment (once assembled) consists of two main steps:

- A) Canister Preparation
- B) Sampler Piston Priming

I.A) Canister Preparation

The main aim here is to get the volume outside the bag (Figures 3 and 5) entirely filled with water while excluding air as completely as possible, since air drawn through the pumping system may result in irregular fill rates. Instructions for preparation are as follows:

- i) Fill the back of the canisters (i.e. behind the sample bag) very slowly using clean water (approximately 200 ml/min), tapping the canisters occasionally to displace any air trapped in the folds of the bag
- ii) Fill the space around the valve at the top of the canister with water.
- iii) Expel all bubbles possible through the open plug hole
- iv) Insert a male quick-connect into the top and hold vertical to remove any air trapped under fitting.
- v) Replace the teflon tape on the plug threads and reinstall the plug under water (finger tight plus

perhaps one turn with a wrench). Installing the plug underwater minimizes the possibility of trapping air under the plug.

- vi) Connect the water/vacuum line to the top of the canister and pull a vacuum on the bag.
- vii) Disconnect the pump and check that the bag holds a vacuum (particularly if it's a newly rebagged canister).
- viii) Submerge the entire canister under water; connect the tubing to the male quick-connect and hold the tubing end about 10 cm above the water surface.
- ix) Open the stopcock valve on the canister until tube stops dripping. This results in about 10-15 ml of water entering the bag. This mechanically relaxes the bag and provides a water barrier used later in deployment to prevent air from entering the valve and bag.
- x) Close the valve, disconnect the tubing underwater, and the canister is ready for redeployment.

I.B) Sampler Piston Priming

This is harder the first time, or when the samplers have been out of action for a while since air is trapped throughout the hydraulic lines. Again the aim is to rid the system of air. In addition, the piston must be armed for action. There are two sections of the sampler hydraulic lines that are primed; above and below the three-way valve at the base of the sampler (Fig. 5). The tool to perform these operations is a three-way valve with one port connected to a vacuum system with a 20L pre-pump water collection trap, another port connected to a low pressure (4-7 kPa or 5-10 p.s.i.) water supply consisting of a submersible pump in a reservoir of clean water, and the valve's common port with female quick-connect to mate with the three-way valve at the base of the sampler

I.B.1. Fill the tubing section above the 3-way valve

- i) Connect the vacuum/water pumps to the quick-connect on the vacuum port (Figures 3 and 5)
- ii) If there is a lot of air in the tubing above the valve, this section should be evacuated and then flushed with water (step iii), otherwise skip directly to step iii without evacuating the line.
- iii) Push small air bubbles without using the pump. Connect female quick-connect to the top of the tubing section and tap the tubing until all air bubbles have passed out.
- iv) Fill the top of the canister around the fittings with clean water and disconnect the quick-connects at the top of the tube under water with the water still pumping.
- v) Connect the tubing to the canister underwater, avoiding no air bubbles.

Note: It can be very hard to get all the air out when you close the fitting. Any small bubbles will dissolve at depth in any case. However, a couple of remedies for stubborn air bubbles are:

- a) After disconnection, tap the male fitting on the tube on the canister (under water) or flick it with your fingers to get all the air out.
- b) If this fails, remove the fitting, connect it to the tap hose (with not too much pressure) and squirt water through by opening the tube while water's pumping through.

I.B.2. Prime and arm the piston

- i) Put some water above the piston through the top of the sampler. There should always be water here to ensure that the o-ring on the piston remains moist and the sides of the cylinder well-rinsed.
- ii) Connect the vacuum/water pump to the vacuum port.
- iii) For initial priming, use the vacuum pump to suck all the air out, then pump water in to achieve a piston height of 10 to 20 cm. Alternating the two pumps, work the piston up and down a few times to ensure that it runs freely.
- iv) On the final evacuation, stop the piston a 2 to 3 cm above the bottom of the glass cylinder by orienting the perpendicular of the 3-way valve away from the vacuum port.
- v) Put a spacer block in place along side the springs on the top of the sampler.
- vi) Disconnect the water/vacuum pump and replace it with a female quick-connect piece as vent.
- vii) Connect the lanyards and discharge water through the vent by opening the 3-way valve (perpendicular downwards) and pushing down on the lever arm until it is stopped by the spacer block.
- viii) Turn the 3-way valve so perpendicular is away from the vent tube, remove the 3-way valve pin and the spacer block.
- ix) Reset the stopwatch to zero and recock the watch stop mechanism

I.B.3. Repriming between casts

- i) If full canisters are removed and replaced within a reasonable time (an hour or so), the quick-connect above the capillary can be plugged straight into the canister without introducing any air. After longer times, water in the fitting evaporates and problems with bubbles can be encountered.
- ii) Pistons need not be exercised, so just connect the vacuum and go to step iii) of section 2.

II. MULTICHAMBER SAMPLER PREPARATION

II.A) Carousel Preparation

Set up (2) syringe carousels with (25) syringes each. Place one readied syringe in each of the blue clips attached to the aluminum ring. It's best to decide on a filling order that makes sense for the operator. Set up of each syringe consists of ensuring that the piston moves freely in the barrel and placing the water-filled stopper/tubing onto the back of the syringe. A sink filled with clean water helps in this operation. This is a micro gear pump! The gears push only about 0.084 ml/rev (Very Small Teeth! Optionally 0.017 or 0.042 ml/rev gears

for lower pumping rate ranges) so make sure that clean, particle-free water is being passed through the pump. If fouling is suspected, the gears in the case under the barbed nylon fittings can be cleaned with a soft toothbrush and some isopropyl alcohol. Exclusion of air in the carousel sampling system is critical; air should never be drawn through the pump nor remain in the tubings or syringes for deployment.

- i) On initial use, check that all the pistons are running smoothly in their syringes. Wash in water or dilute detergent until this is the case. A soft scrub pad also helps free up a sticky syringe. Don't use a syringe if it repeatedly gets stuck since that simply translates into a missed sample.
- ii) Fill the syringes (without pistons) with water. This is best done very slowly, by gradually sinking the syringe (valve downwards) into a bucket of clean water.
- iii) Rinse the piston, wiping it under water to remove any clinging air bubbles.
- iv) With syringe and piston underwater (i.e. no bubbles), insert latter into former. It is best to keep the syringes and pistons in matched pairs even though they are supposed to be interchangeable.
- v) Hold the syringe up and allow the piston to fall freely to expel all but about 2 ml of the water in the head of the syringe. It's important that the piston be moving freely since the pump will not overcome a "jammed" piston. Practice and patience may be necessary.

Note: The ~2 ml of water allows a droplet to hang from the valve tips when deployed to minimize air in the samples. The platen that secures the stoppers into the syringes has springs attached which gently squeeze the stopper/syringe providing positive pressure in the water hydraulic system and pushing out the ~2 ml to keep air out of the valve and syringe.

- vi) Close the 3-way valve on syringe
- vii) Take the tubing with stopper and quick-connect attached and rinse the stopper well, as it tends to get slimy.
- viii) Attach a loose female quick-connect to the male end on the 1/8" tubing, and jiggle tubing under water until it is entirely free of air bubbles. Be careful to knock the bubbles out of the quick connect too. Both male and female quick-connects have a shut-off valve built in so there's no flow through either half when not mated together.
- ix) Still under water, push the stopper into end of the syringe.
- x) Remove the female quick-connect.
- xi) Put the syringe in place on the carousel and note the syringe number and its position on the carousel.

Note: Numbers tend to rub off the syringes. It is better to write on tape and stick that on the syringes. With practice a carousel of syringes can be prepared in about 30 minutes.

- xii) Secure the platen to the carousel when all the syringes are prepared. Be certain none of the tubings are pinched by the platen or unduly kinked. Don't tighten the wing nuts too tightly at this point. They should be tightened just before opening the valves at the time of deployment. At this point, the platen is there merely to hold the stoppers in the syringes. Screw down the wing nuts on the platen positively to get uniform pressure but sparingly to avoid blowing the 1/8" tubing off the stoppers.

II.B) Valve/Pump Preparation

The valve, pump and tubing system is primed with clean water. Priming needs to be done only for the initial setup if all goes well. Refer to pages 9 and 30 of the McLane Research manual for details on using the "Loading the Syringes" section of the software. Install the tubings on the valve head by finger-tightening the nut/ferrule. It's only plastic threading so use extra caution not to cross-thread or over-tighten. Try another nut/ferrule if it's not going well. There is a check valve in the tubing at the "home" position which ensures that the pump prime is not lost when the sampler is idle in air. If you suspect that the sampler will sit idle in air on other ports then a check valve should be installed in those lines too. Take note to install the tubings in labeled order. Start with the "home" position, directly above the pin hole on the side of the valve and proceed, in diagonal up-down fashion in a clockwise sense until all fifty tubes are installed. This will also be the pumping order. A spare male quick connect inserted into the female quick connect on the valve tubing allows water to flow through the tube while priming. This spare male quick connect (or several) can be removed and repositioned to the next tube to be pumped while going through the priming sequence.

Note: Connecting and disconnecting the quick-connects at ANY time should be done underwater to minimize entrapping air in the tubing. Be careful! Bubbles tend to sit inside both the male and female halves of the quick-connect. Tap the connectors against the side of the water basin to remove these bubbles before attempting to mate the connectors.

II.C) Connecting/Disconnecting the Valve and the Carousels

It is probably best to wait to connect the carousels to the multiport valve until the time schedule, trigger setup, and computer equipment are working. It's much easier to test the system by pumping water in and out of beakers or buckets than it is to recock all the syringes each time. Remember to always pump water when testing the pump; never air! It's allowed to move among valve ports in air or to move valve ports without pumping between movements. For initial setup and testing, remove the pump from its position on the pump/valve plate and submerge it in a bucket of water next to the valve.

It is best to connect the carousel syringe tubing to the valve tubing in the order of sampling so order can be made of the many tubings. As noted above, each connection or disconnection of the quick-connects should be performed under water to minimize air bubbles. A bucket of water can be moved and positioned strategically around the valve while mating the tubing.

III. EXTRACTING SAMPLES

III.A) Canister Samples

Canisters from the integrating samplers are placed in a rack when they are removed from the samplers upon retrieval. The following are instructions for extracting samples for analysis in the lab.

- i) Put a full canister rack on the benchtop.
- ii) Connect a pressurized water supply to the top quick-connect of the canister and install a 1/8" tubing between the valve at the bottom to the three-way valve on a clean sample syringe. The third outlet of the valve on the syringe is connected to 1/8" tubing waste line.
- iii) Open the canister valve with the syringe valve open to waste and flush the line with sample water.
- iv) Switch the valve to expel the water in the syringe.
- v) Switch the valve to fill the syringe with 10 to 20 ml of sample.
- vi) Repeat flushing 3 times, ensuring that all air is purged from the syringe.
- vii) Fill the syringe with 50 ml of sample and close the valves.
- viii) Record the syringe number on the cast sheet.

III.B) Carousel Samples

Sections III.B and III.C are the methods used during NATRE. The set up is depicted in Figure 6 for this procedure. There have been improvements to the procedures for the extraction of carousel samples since the NATRE project. The new methods described in Section III.D supplant the NATRE procedures of Sections III.B and III.C.

- i) Clamp a clean analysis syringe with the valve downwards on the board as shown.
- ii) Connect a short piece of tubing with a three-way valve at the end to the syringe.
- iii) Connect the waste tube to the side-arm of the three-way valve.
- iv) Connect the third port of three-way valve to the carousel syringe containing the sample (this syringe has the valve upwards). At this point, the sample is effectively dangling from the clamp stand via a number of fittings, so make sure they're secure!
- v) Connect the quick-connect at the end of the tube on the carousel syringe stopper to the water supply.
- vi) Open the three-way valve and the analysis syringe valve to drain water through the waste line and to flush the connecting tubing.
- vii) Turn the three-way valve to close the waste line.
- viii) Sample should start filling the analysis syringe, pushed by the head on the water supply.
- ix) If the carousel sample contains air, then this air must be transferred in addition to 50 ml of water.
- x) If the carousel syringe was air-free, transfer 50 ml of sample.
- xii) Close the valve on the analysis syringe, which is now ready for a headspace of nitrogen to be introduced.
- xiii) Disconnect the quick-connect fitting from the pressurized water supply.

- xiv) Soak the carousel syringe prior to preparation for the next cast.

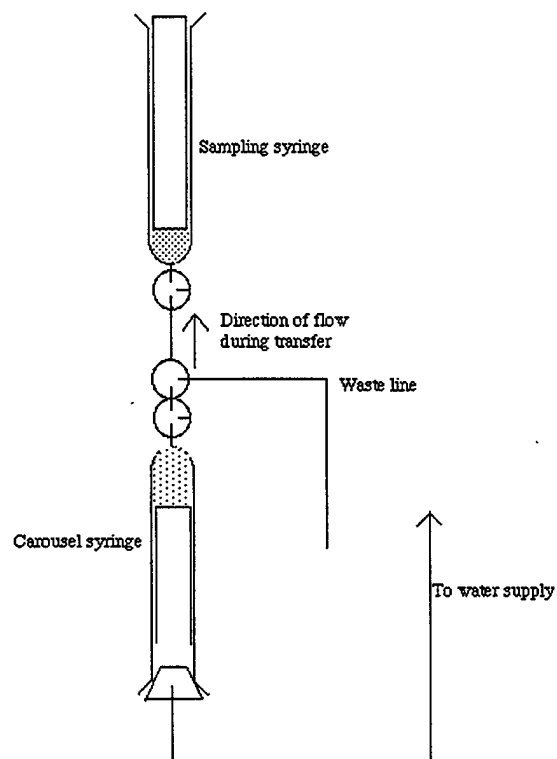


Figure 6. Schematic of the carousel sample syringe transfer setup.

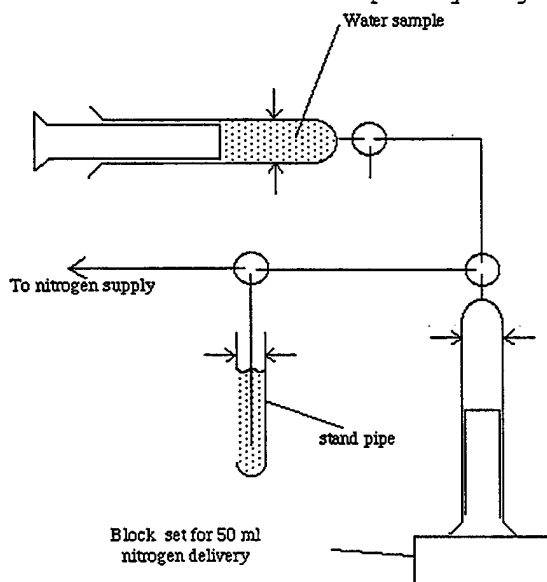


Figure 7. Schematic of the headspace nitrogen transfer setup.

III.C) Nitrogen Introduction

The set up is depicted in Figure 7 for the introduction of nitrogen to a sample syringe.

- i) Ensure that the water level in the bubble tube is at marked level and that the tube is correctly positioned on the board.
- ii) Open the nitrogen supply until a steady stream of bubbles flows through the water in the bubble tube.
- iii) Close the valve to the bubble tube, and flush the line to the sample syringe three times with 50 ml of nitrogen.
- iv) During the third filling of the vertical syringe, open valve to sample syringe and to bubble tube. After the syringe fills, wait for a bubble stream to appear in the bubble tube, then push the nitrogen into the sample syringe, close the valves and send the sample syringe for headspace equilibrium and analysis.

III.D) Carousel Syringe Rocker

This is a new system for extracting samples from the multichamber sampler carousels that was used during the spring 1996 Brazil Basin Tracer Release Experiment. This procedure replaces much of that described in Sections III.B and III.C.

A special frame was constructed to which a complete syringe carousel is bolted after a cast. The frame is an oversized cube with the carousel contained within. With the syringe valves pointed down to retain any bubbles within the syringe, a low-pressure water source is connected via a male quick-connect and three-way valve to the hydraulic tubing on the back of each of syringe on the carousel. Sample water is exhausted from the syringe to a preset level of about 20 ml. A clean nitrogen source is connected to the syringe valve and the three-way valve on the low-pressure water source is turned to allow water to flow out from behind the syringe piston to waste. A measured aliquot of headspace nitrogen is introduced into the syringe. One side of the cube frame is shaped into an approximately 60° arc of a circle, similar to the rocker on a chair. With the rocker side on the bench, the carousel syringes lay horizontal and an agitated rocking motion for a several minutes effectively transfers the SF₆ from the water to the headspace nitrogen. The headspace nitrogen can then be extracted and analyzed by turning the carousel so that the syringe valves are up and forcing the gas out with the low-pressure water supply.

IV. RECYCLING OF SYRINGES AND CANISTERS

IV.A) Syringe Washing

When the syringes come back from analysis, rinse both piston and cylinder 5 or 6 times with clean water. Store closed with 10 to 20 ml of water (and no air) up-side-down in buckets of water.

IV.B) Canister Backfilling and Recycling

Sampled canisters may have one of two fates, depending on the results of the SF₆ analysis for the canister. Criteria for "high" or "low" SF₆ levels are set by the analysts. Both procedures start by draining the sample from the canister and then either:

1. Recocking (low levels of SF₆),
- or 2. Backfilling once or twice with nitrogen (higher SF₆ concentrations) before recocking.

IV.B.1. Draining and Recocking

- i) Connect a water supply to the quick-connect at the top of the canister.
- ii) Connect a drainage tube to the valve at the bottom.
- iii) Open the bottom valve and allow the sample to drain until flow stops.
- iv) If no backfill is required, go to step vi) of the Canister Preparation procedure.

IV.B.2. Nitrogen Backfilling

- i) Connect a 1/8" tube with quick-connect on to the inverted and drained canister. Dangle this into a 1 L graduated cylinder, with the end of the tube at a fixed level (say the 850 ml mark).
- ii) Connect the nitrogen supply to the canister valve which is now at the top of canister and open the valves.
- iii) Allow about 850 ml of water to be forced by the nitrogen into the cylinder. There is an overshoot after the nitrogen supply is shut off that depends on the gas pressure; this is about 100 ml at 35 kPa (5 p.s.i.), so the nitrogen should be turned off after about 750 ml are collected.
- iv) Record the volume of water collected and the clock time.
- v) Leave the canisters for at least an hour before analysis.
- vi) With the canister upside down, pump water in through the quick-connect.
- vii) Open the bag valve to release nitrogen.
- viii) Go to step vi) of Canister Preparation if only one backfilling is required, or step i) of Nitrogen Backfilling if second backfill is required.

IV.B.3. Canister Rebagging Procedure

Canister sample bags can split or fail to hold vacuum for a variety of reasons. It is good practice to check that every bag holds vacuum before use. If the seal is lost, the canister should be rebagged. Otherwise the sample bags can be reused repeatedly.

- i) Clean both the o-rings on the canister's sample bag plug and the inside of the bottom of the canister with isopropyl alcohol.
- ii) Insert the plug into a sample bag until it sits straight and snug.
- iii) Place the bag and plug into the canister until the first o-ring is in the canister.
- iv) Cut the excess bag material off between the two o-rings of the plug.
- v) Place a generous amount of Dow Corning #4 Compound on the second o-ring and insert the plug into the canister until it is straight and snug.
- vi) Pull a vacuum inside the bag and check that it seals.
- vii) Go to step 1 of Canister Preparation.

V. LABORATORY ROUTINE

V.A) Before a cast

- i) Ensure that enough canisters are ready to go, including extras in case of problems on the wire.
- ii) Prime all samplers available.
- iii) Check that all watches are reset, that all plumbing is correctly connected, and that samplers are as air-free as possible.
- iv) Prepare the cast sheet.

V.B) During a cast

- i) Make sure all samplers and canisters are correctly recorded on the cast sheet, at the correct depth.
- ii) Ensure watches are running on all samplers as they go out to the wire
- iii) Ensure lanyards on samplers are cocked to the niskin before they go to the wire.
- iv) Before the sled goes out, make sure the valves are open on sled samplers and carousel syringes and that all drip on opening. If the carousel syringes don't drip, screw down harder on the retaining wing nuts.

V.C) As a cast comes up

- i) As soon as the sled is on the deck, take a rush sample to be analyzed in order for decisions to be made about the subsequent sampling site.
- ii) If there is someone in the lab, he or she can be removing canisters and replacing them with new ones as the samplers come off the wire.
- iii) Re-prime all the samplers. This should be a relatively quick process once the casts get going.
- iv) Reset all watches.
- iv) Don't forget to prime and cock the samplers on the sled.

V.D) With a new set of samples

- i) Transfer and analyze the canister samples first.
- ii) Don't discard any sample until all the analyses are done, and preferably wait until a profile has been constructed so that lab error can be eliminated as a source of problems with the data.
- iv) If SF₆ was found in the sled canisters, transfer and analyze the carousel syringes.
- v) Continue with canister recycling, syringe cleaning etc. In particular, ensure that carousels and enough canisters are ready before the next cast comes up.

VI. SAMPLER ARRAY AND SLED DEPLOYMENT/RECOVERY

VI.A) Deployment

Only necessary personnel should be in the launch area during lifting and over-the-rail operations such as the sampling array (Fig. 1) launch and recovery. Onlookers should stay well out of the way to minimize hazard and confusion. These deck operations require a CTD winch operator and an auxiliary winch operator, two tag line/tugger handlers, one person to direct all deck and winch operations, and an overall supervisor to ensure that the checklist of launch procedures is followed. Since even these people are not always fully occupied during

the launch/recovery process, they can help handling samplers as needed or depart the deck after their contribution is complete. Approximately 45-60 minutes are required to deploy an array of 24 samplers, 4 SeaCats, and the sled.

It was useful at times to have a pulpit, or "hero platform", overhanging the rail when deploying or retrieving the array. On the RRS Charles Darwin the array was deployed off the starboard waist where the hull drops straight down from the rail. A pulpit was needed so the array could be held away from the hull to prevent smashing equipment while we were hanging gear on the wire. Sampler spacing and freeboard were factors in choosing a pulpit since with high freeboard and small sampler spacing we could have several samplers sway in the air at one time. On the R/V Oceanus we deployed off the stern. Here the hull cuts away below deck height, sample spacing was greater, and there is less freeboard. The pulpit on Oceanus became more of a hindrance and was set aside.

The sinking rate of the array was limited to about 20-25 m/min. Careful attention to the wire tension, particularly in rough weather, allowed the winch operator to maximize the descent speed without kinking the CTD wire. The array would be towed along the density surface at speeds of up to 2.5 knots, resulting in wire tensions up to 450 kg. Tow speed was limited by the desire to minimize wire angle and by strumming. Wire angle at the sheave was approximately 45° at 2.3 knots. The vibration energy of strumming was apparently being concentrated at the top sampler in the array. Strands of the CTD cable continued to break underneath the sampler attachment. The CTD cable had to be reterminated after every 10 or so casts when towing at 2 to 2.5 knots. This problem was somewhat alleviated by attaching the uppermost sampler with a bookclamp lined with tygon tubing. This problem did not appear at a speed of 1 knot.

For deployment off the starboard side, the ship is oriented with the wind on the starboard bow and minimal headway is maintained for control of the ship. The on-deck procedures are as follows:

- i) Using an auxiliary winch, a weight of 225-450 kg (500-1000 lbs.), depending on desired tow speed, is lowered on a 50 m X 6.4 mm (1/4") cable. This cable, which was previously marked by threading in a piece of color-coded yarn at specified intervals, supports the lower section of the array. Lower it over the side to a point below where the lowest sampler will be attached. Attach a pinger with a messenger-activated switch below all the samplers to confirm that the bottom array's samplers all fired.
- ii) Attach the lower array samplers and Seacat CTDs until the pear ring at the end of the 50 m cable is level with the rail and away from the hull. This allows the sled pennant (~2-3m wire) to be attached while the lower array samplers are kept off the hull.
- iii) Put the sampler in place on the CTD wire above the sled before lifting the sled. A second messenger-activated switch wired to a channel on the CTD is also attached to the CTD wire just above the sled. This switch confirms that the samplers of the upper half of the array have fired.
- iv) Slide the sled to the rail and attach the sled pennant to the pear ring with a shackle.

- v) Place the A-frame pulley directly over the sled and secure tag lines fore and aft on the sled.
- vi) Lift the sled over the rail level.
- vii) Move the A-frame outboard until the sled is clear of the ship.
- viii) Slowly lift the sled until the CTD wire takes the tension on the lower array wire.
- ix) Let the auxiliary wire go slack and disconnect it at pear ring. Secure the auxiliary cable out of the way.
- x) Lift the sled to a point where the sampler immediately below the sled and its messenger can be deployed on the sled pennant while a second messenger lanyard from this sampler is arranged which bypasses the pear ring to activate the samplers of the lower array. Make sure the tag lines and cable are well secured and stabilized before sending someone under the load.
- xi) Lower the sled and deploy the upper array samplers at the appropriate locations on the wire. Be sure to keep the tag lines on the sled until the sled is well below the surf zone to minimize surging and damage to the equipment.

VI.B) Recovery

The recovery procedure is the reverse of the deployment procedure. Attach the tugger lines using pickup poles as soon as the sled can be reached.

APPENDIX B

Integrating Sampler Parts and Suppliers List

Parts List for Integrating Sampler (1991 Prices)

Part ID	Vendor	Model #	#/ sampler	Cost	Cost/sampler
Honed Glass Cylinder (3.25 x 3 x 11")	Wilmad Glass		1	175	\$ 175.00
Bal Seal Spring-loaded, teflon o-rings	Bal Seal Eng. Co. Inc.	416LB-334-HST	1	60	\$ 60.00
Neg'ator Constant tension springs (7.92lbsf.)	Stock Drive Products	3X50-SH12P36	2	3.85	\$ 7.70
Timex "Ironman" Wrist Watch	Bradlees	63731	1	22	\$ 22.00
3/8" Titanium Tie Rods			4		\$ 10.00
Plastics For Endcaps, etc.					\$ 50.00
Acrylic Tubing (3.25 O.D. x 2.75 I.D.)			~18"	8.55/ft	\$ 12.83
Acrylic Rod (3" O.D.)			~4"	144/4'	\$ 12.00
Acrylic Sheet (0.5 x 48 x 72")			4 x 4"	145.20/sheet	\$ 0.50
Vacuum Tubing (1/4" I.D.)			1'	95.35/50'	\$ 1.91
Tygon Tubing (1/8" I.D.)			2'	25.65/50'	\$ 1.02
Tygon Capillary Tubing (0.030" I.D.)			5'	111.45/500'	\$ 1.11
Tie wraps (6")			5	30.10/1000	\$ 0.01
Nylon 3-way valve with 1/4" barbs	Fisher	14-169-1P	1	16.85	\$ 16.86
Tubing Connectors (1/4" Tubing)	Fisher	14-169-1E	2	14.77/20	\$ 1.48
1/4" MNPT to 1/4" barb	Fisher	14-170-15C	1	2.60/10	\$ 0.26
Quick Connect to 1/8" Tubing (Male)	Cole Parmer Co.	YB-06830-56	1	4.21	\$ 4.21
Quick Connect to 1/8" Tubing (Female)	Cole Parmer Co.	YB-06225-40	2	4.28	\$ 8.56
Quick Connect to 1/4" Tubing (Male)	Cole Parmer Co.	YB-06478-01	1	4.68	\$ 4.68
Quick Connect to 1/4" Tubing (Female)	Cole Parmer Co.	YB-06360-40	1	4.9	\$ 4.90
Stopcock w/ luer fittings	Cole Parmer Co.	YB-06359-70	2	42.75/20	\$ 1.71
1/4" MNPT Plug	Cole Parmer Co.	YB-06360-80	2	1.80/10	\$ 0.36
Female luer to 1/8" barb	Cole Parmer Co.	YB-06359-72	4	8.00/25	\$ 12.50
Male luer to 1/8" barb	Cole Parmer Co.	YB-06359-17	4	8.00/25	\$ 12.50
5/16-28 to male luer lock	Popper and Sons Inc	6188	2	42.60/12	\$ 7.10
Male luer lock to 0.030" I.D. capillary	Popper and Sons, Inc	6233	4	40.75/12	\$ 6.79
Machining	B & C Machine Co.			14,000/31	\$ 400.00
Sampler Bags	Pollution Meas. Corp.	"ID BAG"	10	5	\$ 50.00
Buna-N O-Rings for Canister		2-146	2	0.3	\$ 0.60
Buna-N O-Rings for bottom end cap		2-149	1	0.3	\$ 0.30
Oil Diaphragm		4-100-44-C(-)59	1	10	\$ 10.00
S.S. Hose Clamps (9,3-Niskin; 3,2-Canister)	Bellofram Corp.	Make-a-clamp	4	0.25	\$ 1.00

Part ID	Vendor	Model #	#/ sampler	Cost	Cost/sampler
8-32 x 3/4", fil., Bott. Tie Rods			4		
8-32 x 3/8", flat, piston heads			6		
8-32 x 2.75", fil., top tie rods			4		
8-32 x 1/2", fil., clevis mounting			2		
8-32 x 1/4", pan, hose clamps			16		
8-32 x 1/4", seal, oil fill			1		
#8 washers, hose clamp screws for canister			2		
6-32 x 1/2", fil., Belo-fram retainer			8		
6-32 x 3/8", fil., Pivot block mounting			2		
6-32 x 1/2", fil., watch activator set screw			1		
10-32 x 1/2", fil., post screw			1		
10-32 x 1/2", fil., set screw for nipple mount			4		
10-32 x 1/4", pan, spring fastener screws			2		
1/4-20 x 3/4", fil., Niskin/can cradle mount			8		
1/4-20 Nylon Post screws			3		
1" Shoulder Screw, clevis pivot	Winfred M. Berg	PL-25-3	1		
1/2" Shoulder screw, rocker pivot	Winfred M. Berg	PL-9-3	1		
Misc. hardware/missing estimates					
				TOTAL:	
					\$ 50.00
					~\$950

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16. Abstract (Limit: 200 words) Conventional "spot" sampling of patchy distributions of oceanic constituents can lead to sampling errors. Interpretation of results based on data of disparate temporal or spatial resolution can be difficult or impossible. This report discusses the design and performance of two water sampling devices which attempt to minimize these problems. The devices were created for open ocean tracer release experiments, but can be used for other experiments where inhomogeneity is anticipated. The first sampler is a mechanically-operated, variable-rate integrating water sampler which acquires a time-averaged sample. The sampler incorporates features of both the spring-driven and the hydraulically-driven samplers described by Ledwell et al., 1991. The second sampler is a multichamber sampling system incorporating a battery powered pump and valve system made by McLane Research, Inc., of Falmouth, Massachusetts. The system consists of a micro-gear pump, a 50-port valve with programmable controller, and carousels containing fifty glass sampling syringes. It can be programmed to sample on a variety of schedules allowing the user flexibility in the field to adapt to changing requirements. A general description, operational instructions, and performance analysis are provided for each sampler system.			
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